Some Advanced ML Features

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Content

- Recap last week
- Some benefits of no side-effects
- Some advanced features
  - Exceptions
  - Module System
  - Imperative Features

Class	Grammar/Meta-Variable	Examples
Identifiers	x, y	a, x, y, x_y, foo1000
Datatype Type constructors	X,Y	Nil, Const, List
Constants	c	2, 4.0, "ff", []
Expressions e	e::= x | c | e_1 e_2 | (e_1, e_2, .., e_n) | | if e_1 then e_2 else e_3 | | let [rec] d_1 and … and d_n in e | match e with p_1 -> e_1 |… |p_n ->e_n	
Patterns	p ::= c | x [:t] | (p_1, …, p_n) | X | X(p)	a:int, (x: int, y: int)
Declarations	d::= p = e | y p [: t] = e | | datatype $Y = X_1$ [of t_1] | … | X_n [of t_n]	let one = 1 let sq(x: int): int
Types	t ::= int | float | string | char | | t_1 -> t_2 | t_1 * … * t_n | Y	
Values	v ::= c | (v_1, …, v_n) | X(v)	

Factorial in ML

```
let rec fac n = if n = 0 then 1 else n * fac (n - 1)

//  val fac : int -> int = <fun>

let rec fac  n : int = if n = 0 then 1 else n * fac (n - 1)

let rec fac = function
   | 0 -> 1
   | n -> n * fac(n - 1)

let fac n =
    let rec ifac n acc =
        if n=0 then acc else ifac n-1, n * acc
  in ifac n, 1
```

Plan

- Basic Programming in ML [last week, this recitation]
- Advanced ML Programming [This week]
- Javascript
- Runtime Management for PL
- Type Inference for ML
- Scala
- …

Benefits of Functional Programming

- No side-effects
- Referential Transparency
  - The value of expression e depends only on its arguments
- Conceptual
- Commutativity
- Easier to show that the code is correct
- Easier to generate efficient implementations

Let-expressions

3 questions:

- Syntax: `let` d_1 `and … and` d_n `in` e
  - Each d_i is any *binding* and e is any *expression*

- Type-checking: Type-check each d_i and e in a static environment that includes the previous bindings.
  Type of whole let-expression is the type of e

- Evaluation: Evaluate each d_i and e in a dynamic environment that includes the previous bindings.
  Result of whole let-expression is result of evaluating e.

Silly Examples

```
let silly1 (z : int) =
    let x = if z > 0 then z else 34
        and y = x+z+9
    in
        if x > y then x*2 else y*y

let silly2 (z : int) =
    let x = 1
     in
        (let x = 2 in x+1) +
        (let y= x+2 in y+1)
// val silly2 : int -> int = <fun>
```

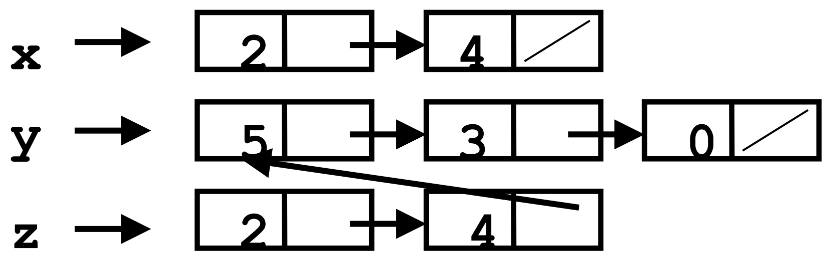
`silly2` is poor style but shows let-expressions are expressions

- Can also use them in function-call arguments, if branches, etc.
- Also notice shadowing

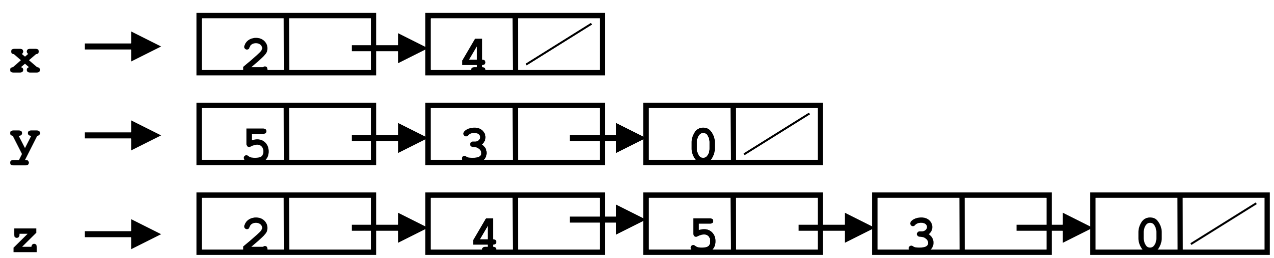
List Example

```
let rec append l1 l2 =
 match l1 with
 | []   -> l2
 | hd :: tl -> hd :: append tl l2
//val append : 'a list -> 'a list -> 'a list = <fun>
```

```
let x = [2;4] //val x : int list = [2; 4]
let y = [5;3;0] //val y : int list = [5; 3; 0]
let z = append x y
  //val z : int list = [2; 4; 5; 3; 0]
```



or



(can't tell, but it's the first one)

Exceptions

- Captures abnormal behavior
  - Error handling
  - Integrated into the type system

```
exception Error // exception Error
let sqrt1 (x : float) : float =
    if x < 0.0 then raise Error
    else sqrt x
// val sqrt1 : float -> float = <fun>
```

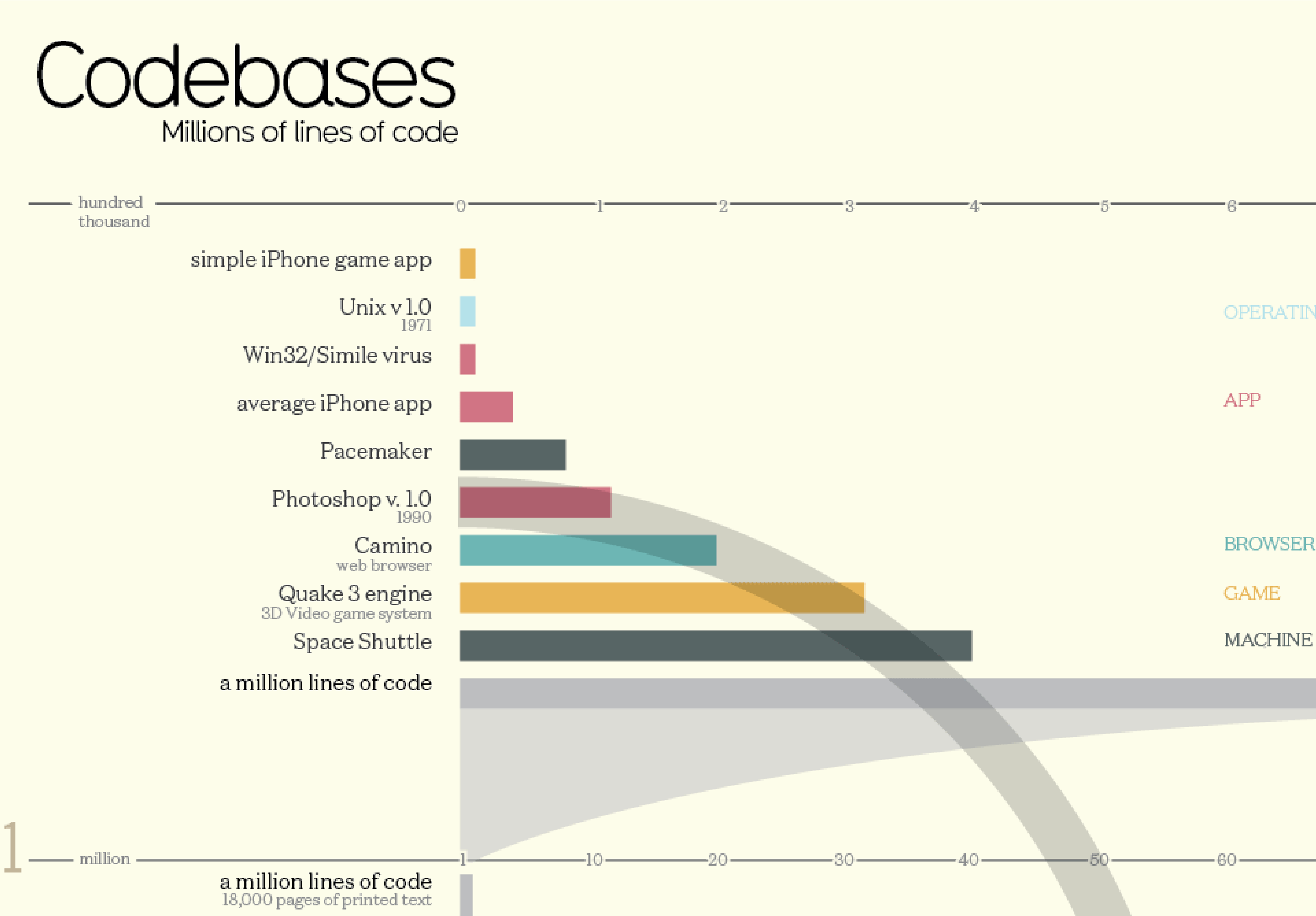
```
exception FailWith of string
```

```
raise (FailWith "Some error message")
```

Question?

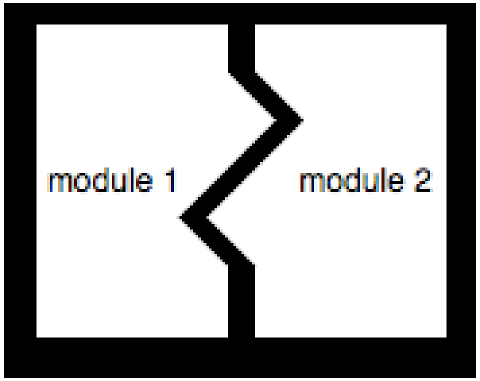
- What’s the largest program you’ve ever worked on by yourself or as part of a team?
  A. 10-100 LoC
  B. 100-1,000 LoC
  C. 1,000-10,000 LoC
  D. 10,000-100,000 LoC
  E. >= 100,000 LoC

http://www.informationisbeautiful.net/visualizations/million-lines-of-code/



Modularity

- **Modular programming**: code comprises independent *modules*
  - developed separately
  - understand behavior of module in isolation
  - reason locally, not globally



Java features for modularity

- classes, packages
  - organize identifiers (classes, methods, fields, etc.) into namespaces
- Interfaces
  - describe related classes
- public, protected, private
  - control what is visible outside a namespace

Ocaml Features for Modularity

- modules organize identifiers (functions, values, etc.) into namespaces
- signatures
  - describe related modules
- abstract types
  - control what is visible outside a namespace

Ocaml Modules

- Syntax:
  module ModuleName = struct *definitions* end
- The name must be capitalized
- The definitions can be any top-level definitions
  - let, type, exception
- Create a new namespace
- Every file myFile.ml with contents *D is essentially wrapped in a module* definition
  module MyFile = struct *D end*
- *Modules can be opened locally to save writing*

```
module M = struct  let x = 42 end
//module M : sig val x : int end
let fourtytwo = M.x
// val fourtytwo : int = 42
```

Stack Module

```
module Stack = struct
  let empty =  [ ]
  let is_empty s = s = [ ]
  let push x s = x :: s
  let pop s = match s with
       [ ] -> failwith “Empty”
     | x::xs -> (x,xs)
end
//module Stack :
//  sig
//   val empty : 'a list
//    val is_empty : 'a list -> bool
//    val push : 'a -> 'a list -> 'a list
//    val pop : 'a list -> 'a * 'a list
 // end
```

```
fst (Stack.pop
(Stack.push 1 Stack.empty))
//- : int = 1
```

Might Seem Backwards…

Java:

```
    s = new Stack();
    s.push(1);
    s.pop()
```

OCaml:

```
    let s = Stack.empty in
      let s' = Stack.push 1 s in
        let (one, _) = Stack.pop s'
```

Abstraction

- Forgetting Information
- Treating different things as identical

Abstraction

- Programming language predefined abstractions
  - Data structures like list
  - Library functions like map and fold
- Programming languages enable to define new abstractions
  - Procedural abstractions
  - Data abstraction
  - Iterator abstraction

Procedural Abstraction

- Abstract implementation details
  - sqrt : float -> float
- List.sort : (‘a -> ‘a -> int) -> ‘a list -> ‘a list
- Abstracts how the functions are implemented
  - Both the implementation and the usage should obey the type contract
  - The implementation can assume the right type
  - Important for composing functions

Data Abstraction

- Abstract from details of organizing data
  - stacks, symbol tables, environments, bank accounts, polynomials, matrices, dictionaries, ...
- Abstract from implementation of organization:
  - Actual code used to add elements (e.g.) isn't Important
  - But types of operations and assumptions about what they do and what they require are important

Ocaml Advanced Modularity Features

- Functors and Signatures
- Functions from Modules to Modules
- Permit
  - Dependency injection
  - Swap implementations
  - Advanced testing

Stack Abstract Data Type

```
module type STACK = sig
    val empty : 'a list
    val is_empty : 'a list -> bool
    val push : 'a -> 'a list -> 'a list
    val pop : 'a list -> 'a * 'a list
end
module Stack : STACK = struct
... (* as before *)
end
```

Stack with Abstract Data Types

```
module type STACK = sig
  type t
  val empty : t
  val is_empty : t -> bool
  val push : int -> t -> t
  val pop : t -> int * t
end
module Stack : STACK = struct
  type t = int list
  let empty = [ ]
  let is_empty s = s = [ ]
  let push x s = x :: s
  let pop s = match s with
      [ ] -> failwith "Empty”
      | x::xs -> (x,xs)
end
```

Summary Modularity

- ML provides flexible mechanisms for modularity
- Guarantees type safety

Side-Effects

- But sometimes side-effects are necessary
- The whole purpose of programming is to conduct side-effects
  - Input/Output
- Sometimes sharing is essential for functionality
- ML provides mechanisms to capture side-effects
  - Enable efficient handling of code with little side effects

Input/Output

```
print_string: String -> Unit
```

```
let x = 3 in
  let () = print_string ("Value of x is " ^ (string_of_int x)) in
  x + 1
;;value of x is 3- : int = 4
```

e ::= ... | (e_1; ... ; e_n)

```
let x = 3 in
  (print_string ("Value of x is " ^ (string_of_int x));
   x + 1)
```

Refs and Arrays

- Two built-in data-structures for implementing shared objects

```
module type REF =
  sig
    type 'a ref
    (* ref(x) creates a new ref containing x *)
    val ref : 'a -> 'a ref
    (* !x is the contents of the ref cell x *)
    val (!) : 'a ref -> ‘a
    (* Effects: x := y updates the contents of x
     * so it contains y. *)
    val (:=) : 'a ref -> 'a -> unit
  end
```

Simple Ref Examples

```
let x : int ref = ref 3
  in
    let y : int = !x
     in
        (x := !x + 1);
        y + !x
// - : int = 7
```

More Examples of Imperative Programming

- Create cell and change contents

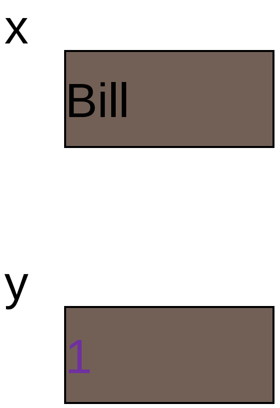
```
val x = ref “Bob”;
x := “Bill”;
```

- Create cell and increment

```
val y = ref 0;
y := !y + 1;
```

- While loop

```
val i = ref 0;
while !i < 10 do i := !i +1;
 i;
```



Summary References

- Provide an escape for imperative programming
- But insures type safety
  - No dangling references
  - No (double) free
  - No null dereferences
- Relies on automatic memory management

Functional Programming Languages

PL	types	evaluation	Side-effect
scheme	Weakly typed	Eager	yes
ML OCAML F#	Polymorphic strongly typed	Eager	References
Haskell	Polymorphic strongly typed	Lazy	None

Things to Notice

- Pure functions are easy to test

```
prop_RevRev l = reverse(reverse l) == l
```

- In an imperative or OO language, you have to
  - set up the state of the object and the external state it reads or writes
  - make the call
  - inspect the state of the object and the external state
  - perhaps copy part of the object or global state, so that you can use it in the post condition

Things to Notice

Types are everywhere.

```
reverse:: [w] -> [w]
```

- Usual static-typing panegyric omitted...
- In ML, types express high-level design, in the same way that UML diagrams do, with the advantage that the type signatures are machine-checked
- Types are (almost always) optional: type inference fills them in if you leave them out

Information from Type Inference

- Consider this function…

```
let reverse ls = match ls with
   [] -> []
   | x :: xs -> reverse xs
```

… and its most general type:

```
:- reverse :: list 't_1 -> list 't_2
```

- What does this type mean?

Reversing a list should not change its type, so there must be an error in the definition of reverse!

Recommended ML Textbooks

- L. C. PAULSON: ML for the Working Programmer
- J. Ullman: Elements of ML Programming
- R. Harper: Programming in Standard ML

Recommended Ocaml Textbooks

- Xavier Leroy: The OCaml system release 4.02
  - Part I: Introduction
- Jason Hickey: Introduction to Objective Caml
- Yaron Minsky, Anil Madhavapeddy, Jason Hickey: Real World Ocaml

Summary

- Functional programs provide concise coding
- Compiled code compares with C code
- Successfully used in some commercial applications
  – F#, ERLANG, Jane Street
- Ideas used in imperative programs
- Good conceptual tool
- Less popular than imperative programs